1.0

2.8   2.5

3.2   2.2

3.6

4.0   2.0

1.1

1.8

1.25   1.4   1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

LEVEL

(12) 400 (2)

(6) XM746 PRACTICE FUZE.

Progress Report

1 December 1979 through 31 January 1980

β S.

Progress Report No. 3

(15) Contract No. DAAK10-79-C-0040

(9) Progress rept. 1 Dec 79-31 Jan 80.
No. 3

(11) 31 Jan 80

Prepared for:

Department of the Army

U. S. Army Armament Research and

Development Command

Prepared by:

MBAssociates

Bollinger Canyon Road

San Ramon, California

94583

222400   80 3   21 047

1.0 INTRODUCTION

This progress report covers the period December 1, 1979 through January 31, 1980 under Contract DAAK10-79-C-0040. This program is for the design and development of the XM746 Practice Fuze Spotting Charge.

In the month of December, (18th and 19th), ballistic testing of the Practice Fuze Spotting Charge was conducted at Ft. Lewis, Washington.

1.1 Object of Test

The primary objective of the testing was to determine which of the three spotting charge candidates, MOD "E", ORI or MBA would reliably produce the best visible smoke cloud in a muddy target area.

1.2 Hardware

All spotting charges were loaded into XM747E2 fuzes and assemblied to the four port 155mm, XM804 projectile, (see Figure 1).

The SW522 (MOD "E") and ORI composition was contained within the fuze, as shown in Figure 2. The MBA configuration was assembled, as shown in Figure 3, (see Table 1 for fuze configuration and Tables 2 and 4 for composition).

The weapon used was a 155mm Howitzer with M4A2/5 charge.

1.3 Testing Matrix

The first phase was to eliminate either the MOD "E" or ORI spotting charge based on their performance; the best performance (MOD "E") was carried forward to Phase II testing along with the MBA spotting charge. The Phase II testing yielded a final candidate for further evaluation in Phase III testing, see Table 3.

1.4 Test Set-Up

To observe and score the spotting charges, F.O. (forward observers) were stationed at 2000 and 4000 meters for Phase I and 1800
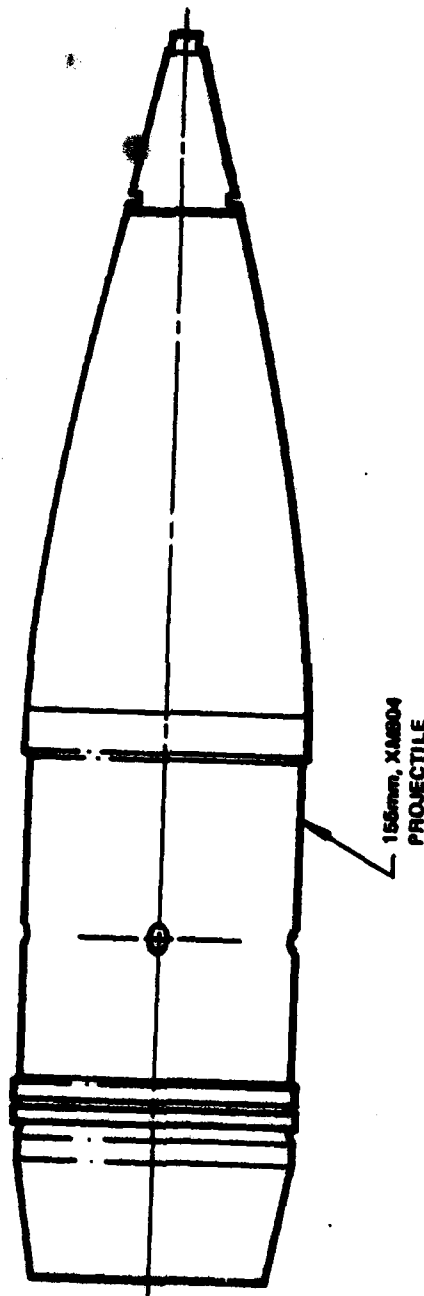
155mm, XM804
PROJECTILE

FIGURE 1
PROJECTILE ASSEMBLY

SPOTTING CHARGE ASSEMBLY
9331926 (17 GM SW422)

BOOSTER CUP
9339997
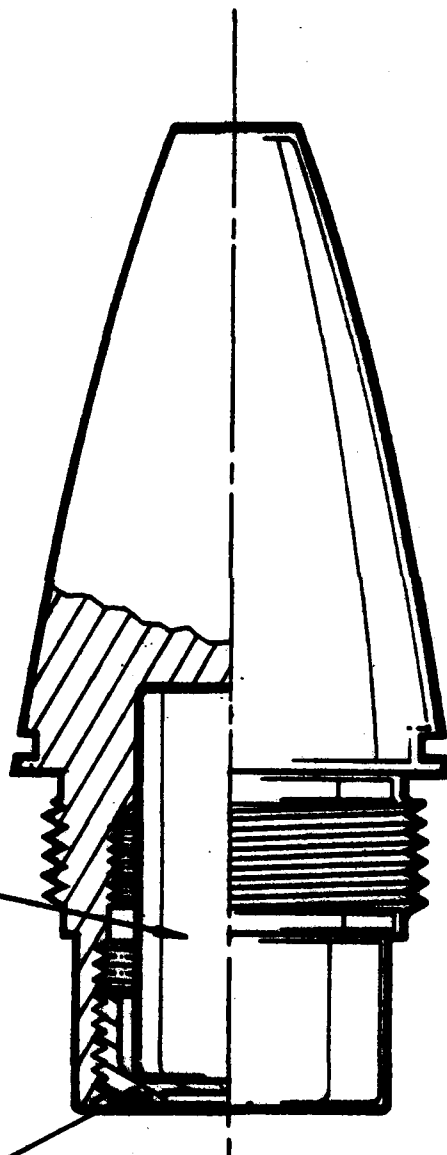
FIGURE 2
MOD "E" AND ORI CONFIGURATION

3
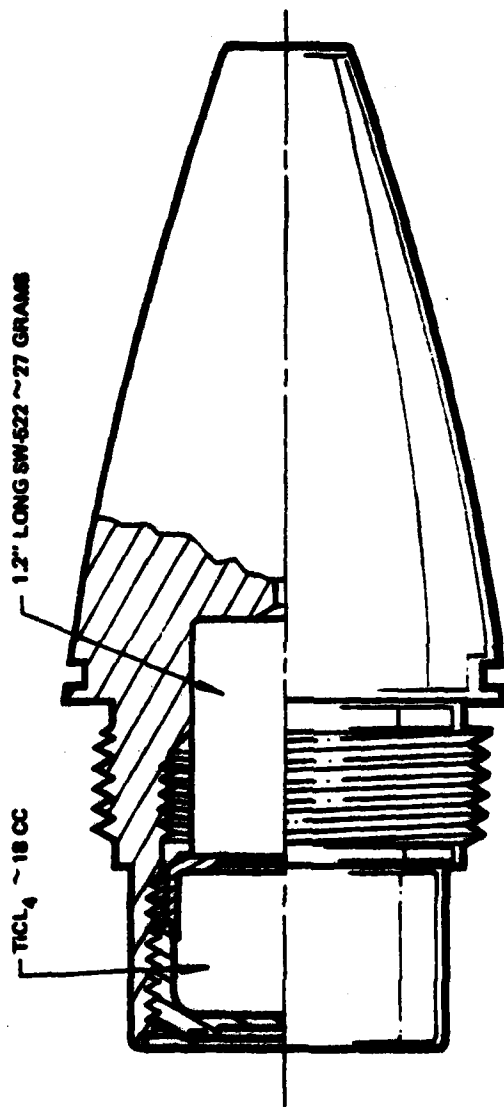
FIGURE 3
TiCL₄/MOD "E" CONFIGURATION

Labels within figure:
- 1.2" LONG SM-522 ~27 GRAMS
- TICL₄ ~18 CC

MBA

3029-16856

TABLE 1

XM747
FUZE CONFIGURATIONS
(FOR FT. LEWIS TESTING)
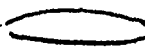
M739 MOD	Description
cont → MOD E is a	Standard M739 Fuze with cap, cross bar holder assembly, M1 Delay Plunger, safe/army assembly and explosive booster removed, loaded with 47 grams ARRADCOM pyro mix SW522. See Table 2 for composition.
→ ORI is the	Same fuze as MOD E except SW-522 smoke composition replaced with a red phosphorous composition. See Table 2 for composition.
→ MBA is	Similar to MOD E except smoke charge consists of titanium tetrachloride ($TiCl_4$) a cold smoke composition which is expelled from the fuze body by an ARRADCOM MOD E smoke ejection charge. See Table 4 for composition.

TABLE 2

DESCRIPTION OF
PYROTECHNIC SMOKE COMPOSITIONS

SW-522:

Ingredient	% by Wt.	Specification
Zinc Dust	40 ± 1	JAN-Z-365
Potassium Perchlorate	20 ± 0.5	MIL-P-217A, GrA, C14
Potassium Nitrate	20 ± 0.5	MIL-P-15613 Cl 2
Aluminum (Atomized)	20 ± 0.5	MIL-P-14067A Type II

ORI

Magnesium	17	MIL-P-14067 Type I
Sodium Nitrate	17	MIL-S-322B, GrB
Phosphorous, Red	63	MIL-P-211A, Cl 2
Zinc Oxide	3	MIL-Z-291C GrA Cl 1

```
                    ┌──────────┐   ┌──────────┐        ┌──────────┐
                    │   MODE   │   │   ORI    │        │   MBA    │
          PHASE     │  8 each  │   │  8 each  │        │  8 each  │
            I       │    LA    │   │    LA    │        │    LA    │
                    └────┬─────┘   └────┬─────┘        └────┬─────┘
                         └──────┬───────┘                   │
        ─────────────────────────────────────────────────────────────
                         ┌──────┴─────┐              ┌──────┴─────┐
                         │  8 each    │              │    MBA     │
          PHASE          │    LA      │              │  8 each    │
           II            │  8 each    │              │    LA      │
                         │    HA      │              │  8 each    │
                         └──────┬─────┘              │    HA      │
                                └──────────┬─────────└────────────┘
        ─────────────────────────────────────────────────────────────
                                    ┌──────┴─────┐
                                    │  5 each    │
          PHASE                     │    LA      │
           III                      │  5 each    │
                                    │    HA      │
                                    └────────────┘
```

LA – QE: 522 mils
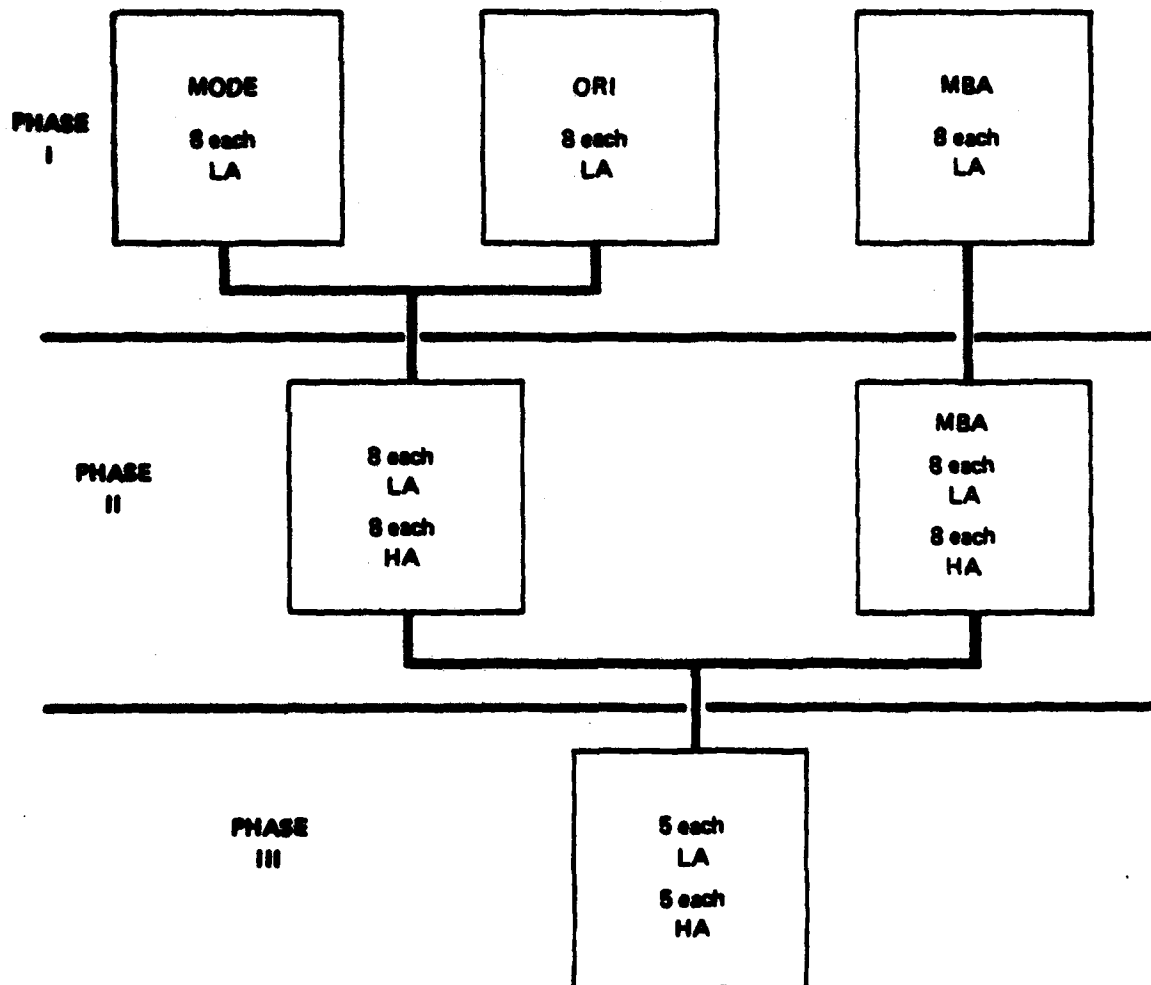
HA – QE: 1054 mils

TABLE 3
TEST MATRIX

7

TABLE 4

TITANIUM TETRACHLORIDE - $TiCl_4$

PHYSICAL PROPERTIES

Chemical Formula	$TiCl_4$
Molecular Weight	189.7
Color, Form	clear liquid
Melting Point	$-30^\circ C$
Boiling Point	$136.4^\circ C$
Specific Gravity ($20^\circ C$)	1.726
Density (lbs./gal.)	14.4
Stability	decomposes in the presence of moist air

SPECIFICATIONS (Weston, Michigan Plant)

Titanium, wt.%	25.0 minimum
Chlorine, wt.%	74.0 minimum
Color	50 maximum

Metal Analysis, ppm

Tin (Sn)	10 max.	Chromium (Cr)	5 max.
Aluminum (Al)	10 max.	Antimony (Sb)	5 max.
Iron (Fe)	15 max.	Arsenic (As)	10 max.
Vanadium (V)	10 max.	Lead (Pb)	1 max.
Silicon (Si)	10 max.	Nickel (Ni)	5 max.
Copper (Cu)	5 max.		

SAFETY AND HANDLING

Titanium tetrachloride must be maintained under inert atmosphere. Nitrogen containing less than 10 ppm oxygen is recommended. Exposure to moisture in the air generates hydrochloric acid and titanium dioxide. Refer to the titanium tetrachloride "Product Safety Information" sheet for safety information, and to the Stauffer brochure "A Guide to Cylinder Unloading."

and 2000 meters for Phase II and III testing. The F.O. were a mix of ARRADCOM, Ft. Sill, Ft. Lewis, Chamberlin, MBA and Yuma Proving Ground personnel, see attachment A.

The scoring system for Phase I was complex. Two F.O's used a number system and 5 F.O's used an alphabetical rating system which related as follows: 1 & U = unobserved, 6 & E = excellent. For the balance of the testing, F.O's used a numbering system 1 through 5 where 1 = unobserved and 5 = excellent. The spotting charges were fired in an alternate order, MOD "E", ORI, MBA.

The tests were recorded on video tape and 16mm camera as follows: Phase I, 16mm camera and video at 2000 meters and video at 4000 meters. Phases II and III, video at 1800 and 2000 meters and 16mm camera at 1800 for the first part of Phase II.

1.5 Weather

Rain was quite persistent for the two days of testing. The weather conditions listed below were submitted by Ft. Lewis.

		Temperature	Humidity	Wind Direction from (True)	Wind Speed
18th.	1100	51°	89%	–	Calm
	1200	52°	89%	–	Calm
	1300	51°	92%	–	Calm
	1400	52°	82%	–	Calm
	1500	51°	86%	120°	4 Knots
19th.	1100	53°	77%	200°	8 knots
	1200	53°	80%	180°	10 knots
	1300	53°	83%	200°	10 knots
	1400	53°	80%	210°	10 knots
	1500	51°	85%	200°	8 knots
	1600	50°	89%	190°	4 knots
	1700	49°	89%	190°	4 knots

1.6 Ballistic Testing

The Phase I testing went as planned on December 8, 1979, with eight each of MOD "E", ORI and MBA spotting charges fired at a low QE of 522 mils. There were 4 F.O.'s at 2000 meters and 3 at 4000 meters.

Based on the scoring of the 7 F.O's (MOD "E" 174,
MBA 143 and ORI 122, summarized in Attachment A), the ORI spotting
charge was dropped from further testing. The smoke clouds for MOD "E"
and MBA, when observed, appeared similar in intensity and duration (see
Figure 3). The flashes observed were judged poor to none for both
configurations. Low priority was placed on the flash due to the fact
that it is a night training requirement.

For the Phase II testing, the F.O's at 4000 meters were
moved to 1800 meters due to the poor visibility and difficulty in spotting
the smoke cloud at the extended range. In total there were 4 F.O's at
1800 meters and 7 F.O's at 2000 meters. No Phase II and III testing was
conducted on December 9th.

In the first part of Phase II testing, 8 each MOD "E"
and MBA fuzes were fired at a low QE of 522 mils. The MBA spotting
charge, with the exception of one round, displayed a smoke cloud which
was judged to be good to excellent in both cloud size and persistence.
The MOD "E" performed much better than the Phase I testing but was
scored significantly lower than the MBA spotting charge. See Figure 5
for a photographic comparison of the typical cloud size.

In the high QE (1054 mils) portion of Phase II testing,
the MOD "E" and MBA spotting charges performed pretty much the same with
many unobserved and relatively poor smoke clouds. The poor performance
was not totally unexpected. Static testing at MBA in September 1979
showed the function time of the MOD "E" spotting charge to be an average
of 2 ms and MBA to be 2.5 ms, from ignition to display of smoke from the
projectile smoke ports. Analysis suggests that on soft ground at high
QE's these times are equivalent to, to slightly longer than, projectile
burial time.

Figure 6 presents ARRADCOM's estimate of the worst case,
most rapid burial condition for the 155mm projectile in question. This
condition exists in deeply saturated light sand soils. The ARRADCOM
model predicts coverage of the smoke ports located 19 inches back on the
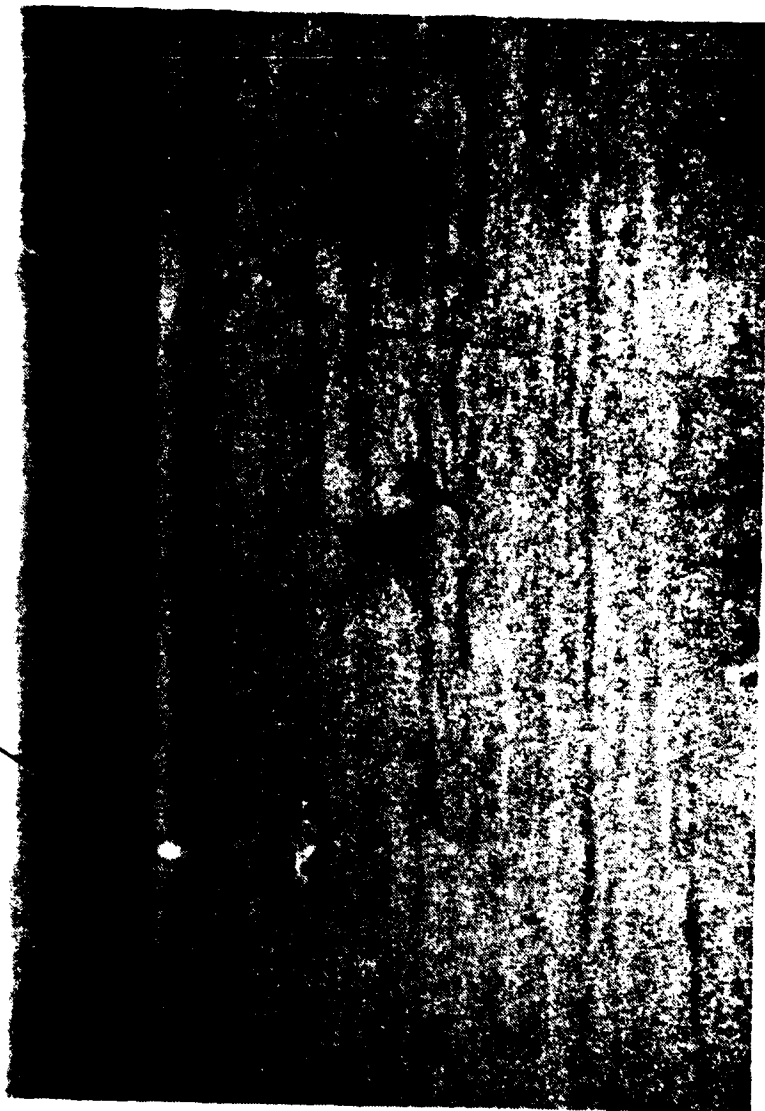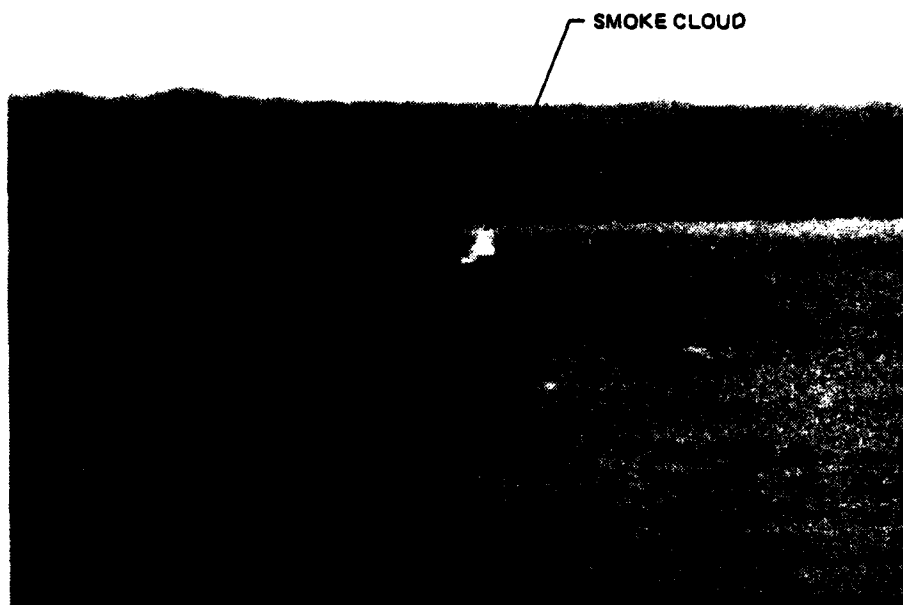projectile, 1.8 milliseconds after impact.

SMOKE CLOUD

FIGURE 4
PHASE I TESTING
TYPICAL SMOKE CLOUD

11

SMOKE CLOUD

MOD "E"

MBA TICL$_4$

FIGURE 5
SMOKE CLOUD COMPARISON

MBA

0710-16985

SMOKE EXIT RELATIONSHIP
TO XM804 PROJ BURIAL
DEPTH AS A FUNCTION OF
EXIT HOLE LOCATION

IMP VEL - 900 FT/SEC
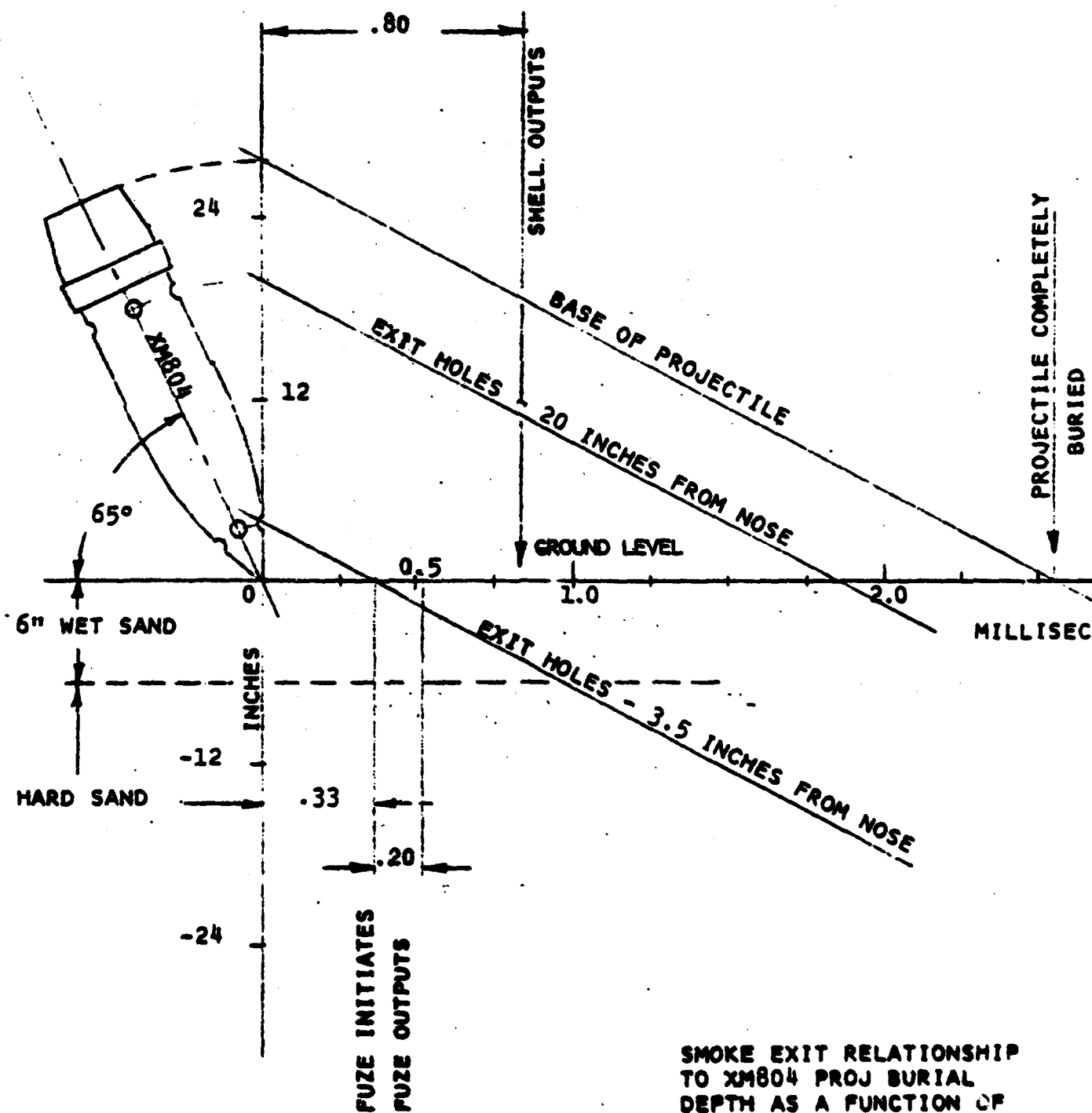IMP ANGLE - 65 DEG
MEDIUM - WET SAND

FIGURE 6

L. POST
NOV. 79

13

Based on the total scoring of the Phase II testing, the MBA spotting charge was selected for the Phase III testing. Due to the poor performance at the high QE firing, it was decided the Phase III firing would be conducted at a low QE of 522 mils.

The Phase III testings were mixed. Three out of the nine firings resulted in smoke clouds judged good to excellent. The remaining six rounds yielded mixed results reported by the observers, per Attachment A, they ranged from fair to no visible smoke cloud.

Rounds 1, 2 & 3 of this test series were assembled to projectiles with 90° ports.

1.7   Conclusions

The smoke clouds produced by the MBA spotting charge, particularly in the low QE Phase II testing, were judged to develop the superior cloud. However, due to the inconsistent performance of both the MOD E and $TiCl_4$ spotting cha ges, further improvement is need. Design requirements to achieve function time repeatability need to be better understood. Quality control and manufacturing methods need to be reviewed in detail and upgraded, or otherwise changed, if it is determined they are causing inconsistent spotting charge performance. Environmental testing should be undertaken to establish the effects, if any, on fuze performance after T&H, transportation, vibration, etc.

1.8   Data Reducation

Figures 7 through 17 show the 90% confidence envelopes for each of the fuze tests with the composite of MOD "E" and $TiCl_4$ fuzes shown in Figures 8 and 9. All data has been normalized by averaging the evaluation with the number of observers, adjusting the evaluation to a common scale, and using zero for a non-visible cloud. The cloud observations are scaled from 0 to 4.

A standard procedure, see Attachment B, was used to determine the statistical quantities for 90% confidence. The curves can be interpreted as follows: The cumulative distribution shows the
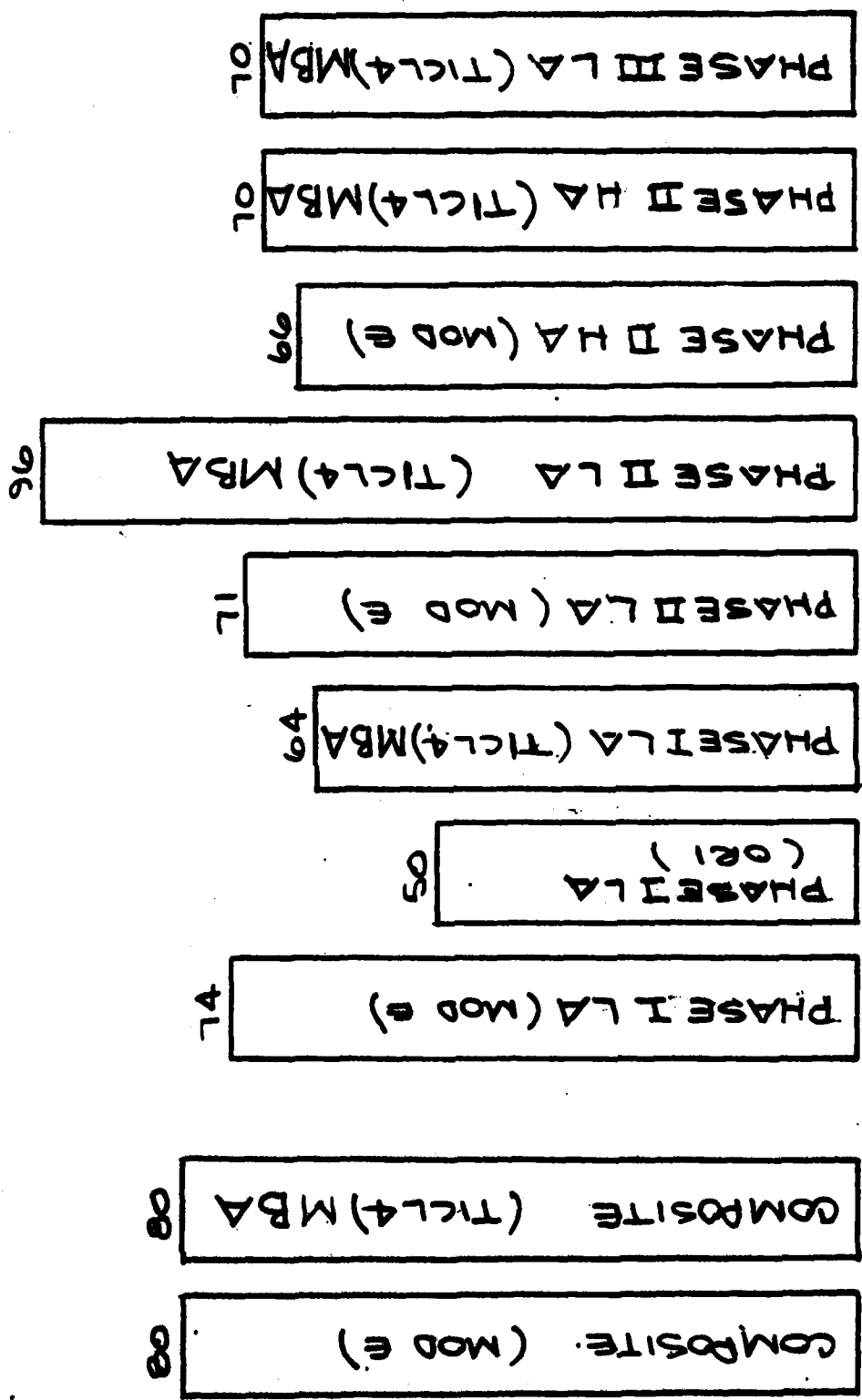
Figure 7 – Comparison of Visible Flares Out of 100 at 90% Confidence
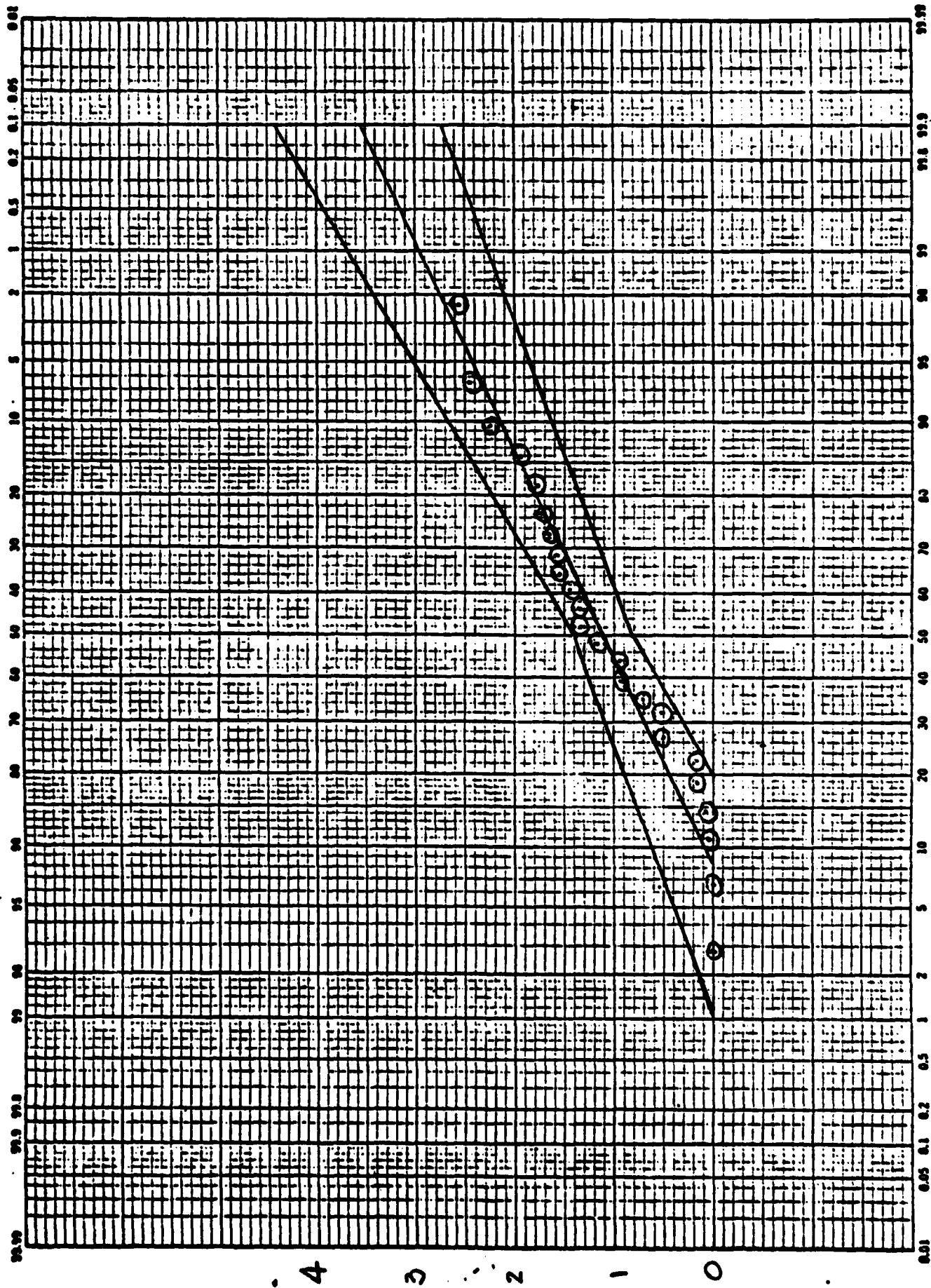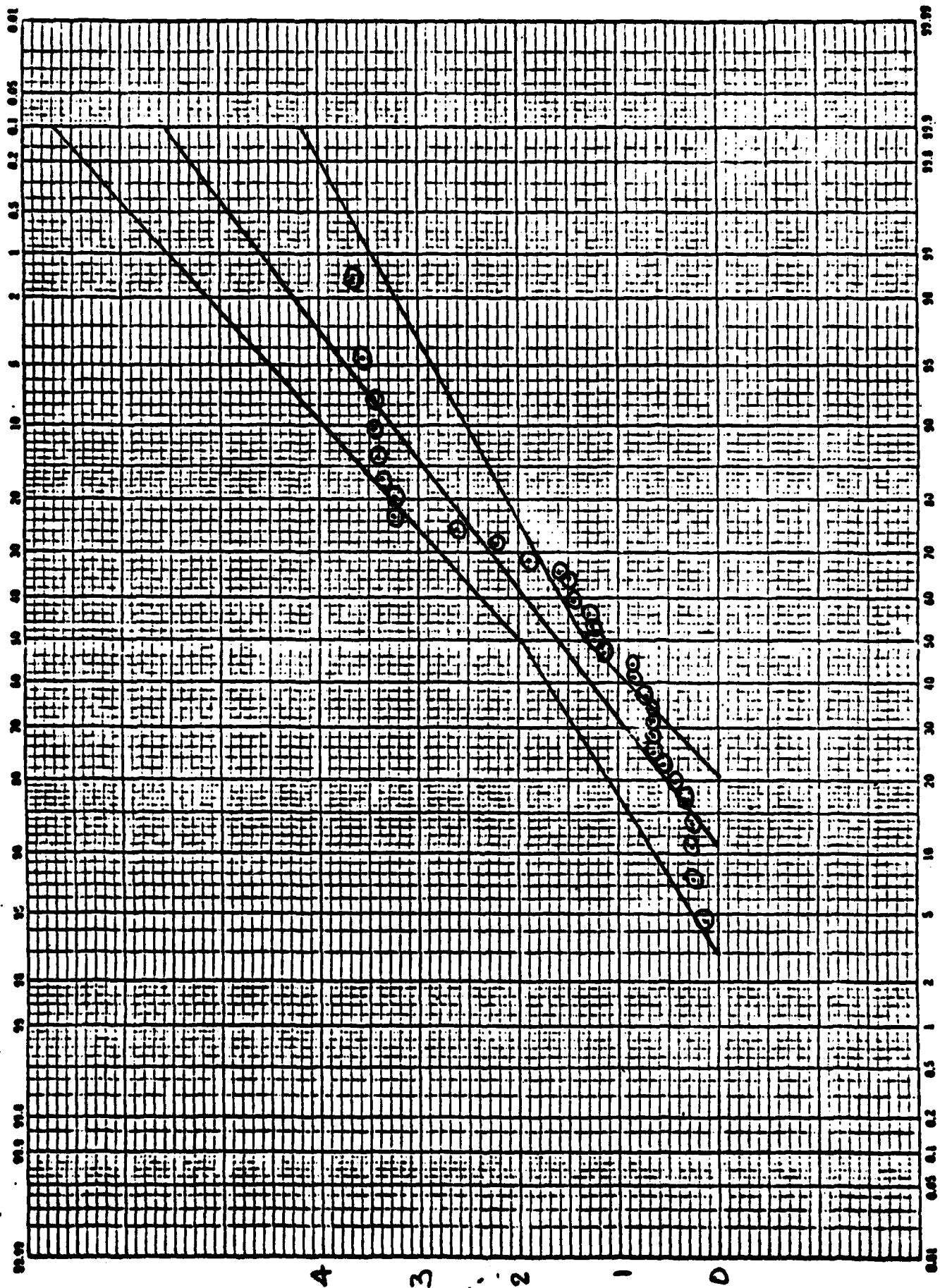
Figure 8 - MOD "E" Composite

16

Figure 9 - MBA Composite

17

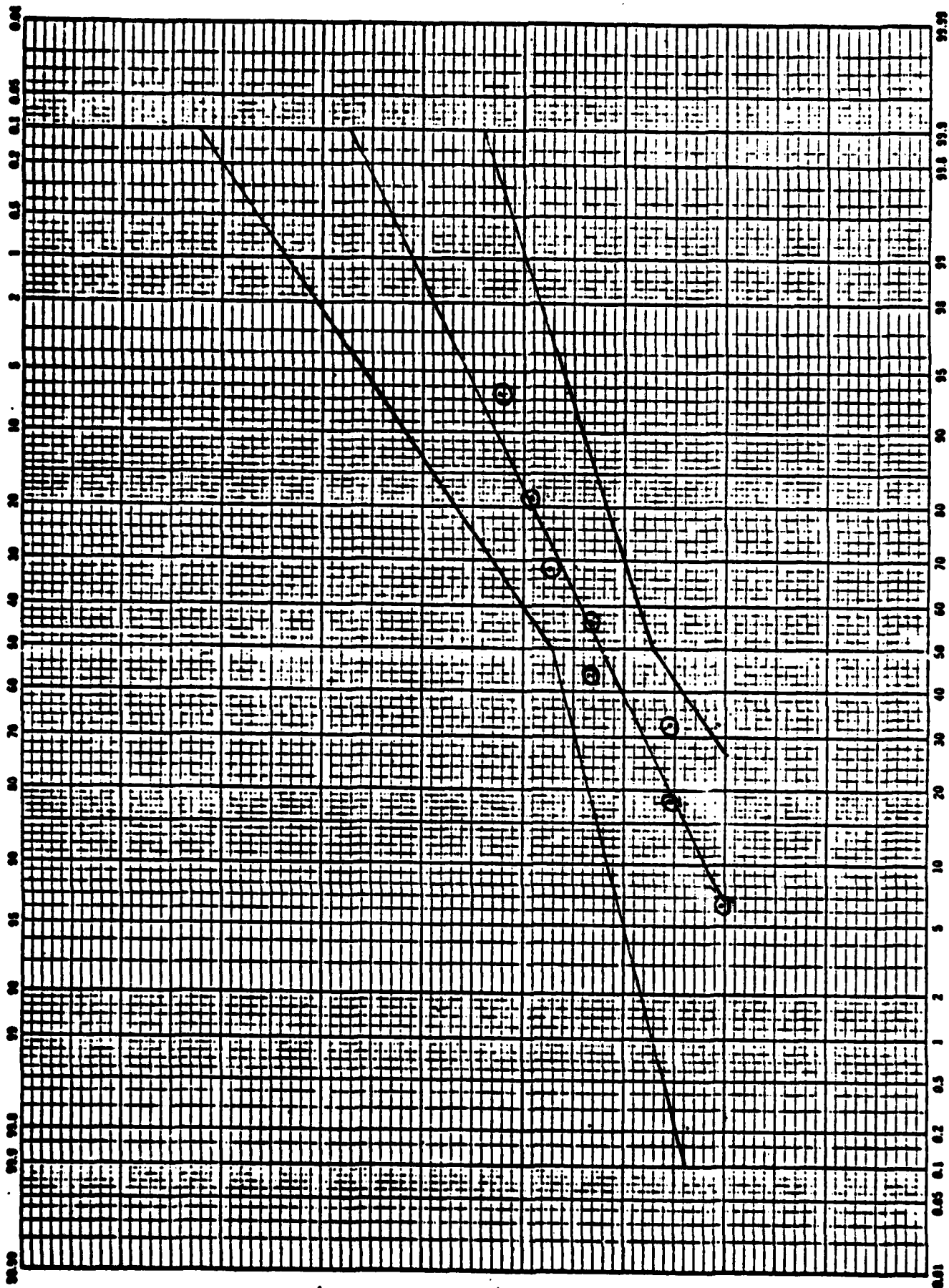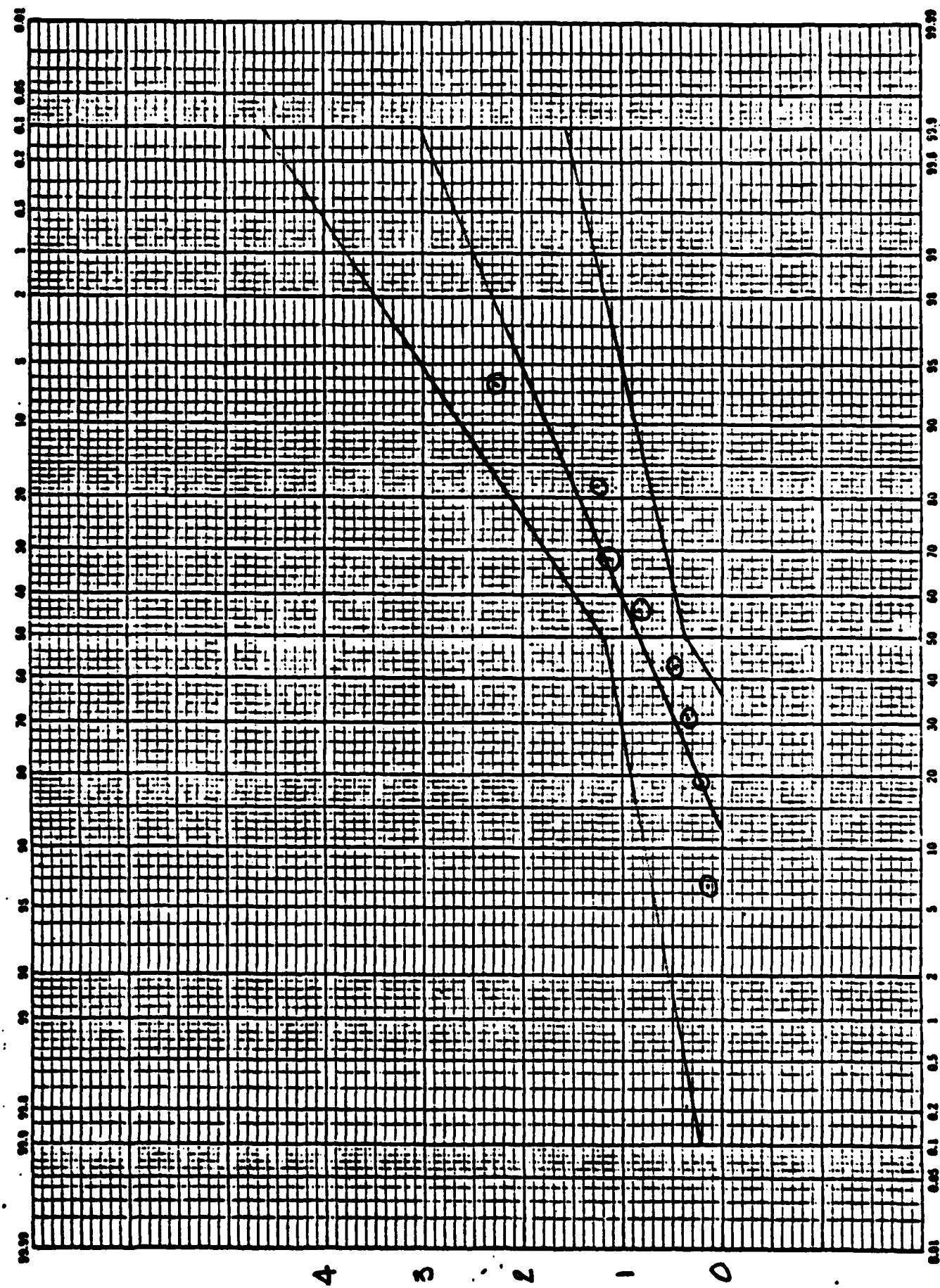Figure10 - MOD "E" Phase I Low Angle

Figure 11 – ORI Phase I Low Angle
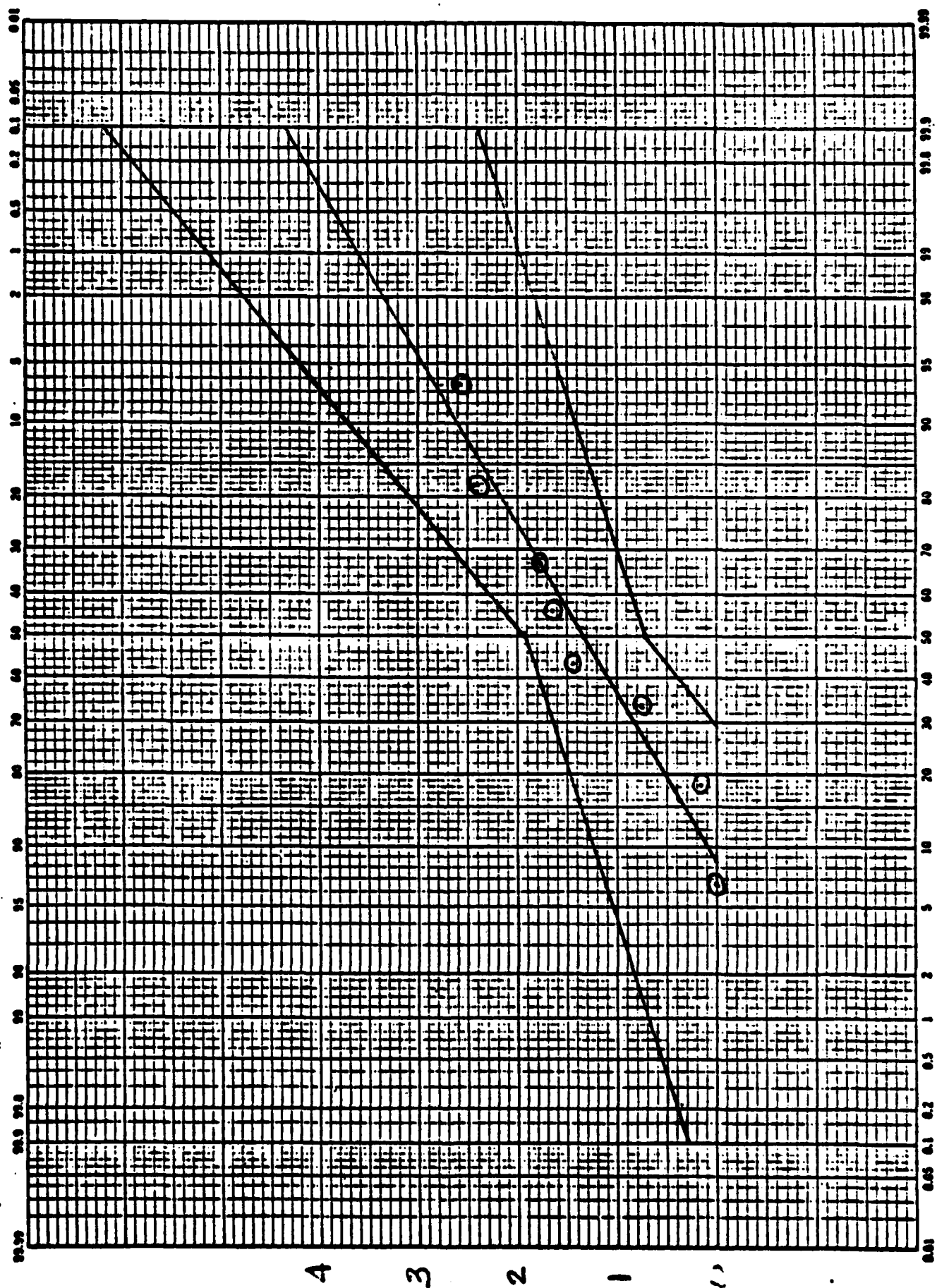
19

Figure 12.- MBA Phase I Low Angle

20

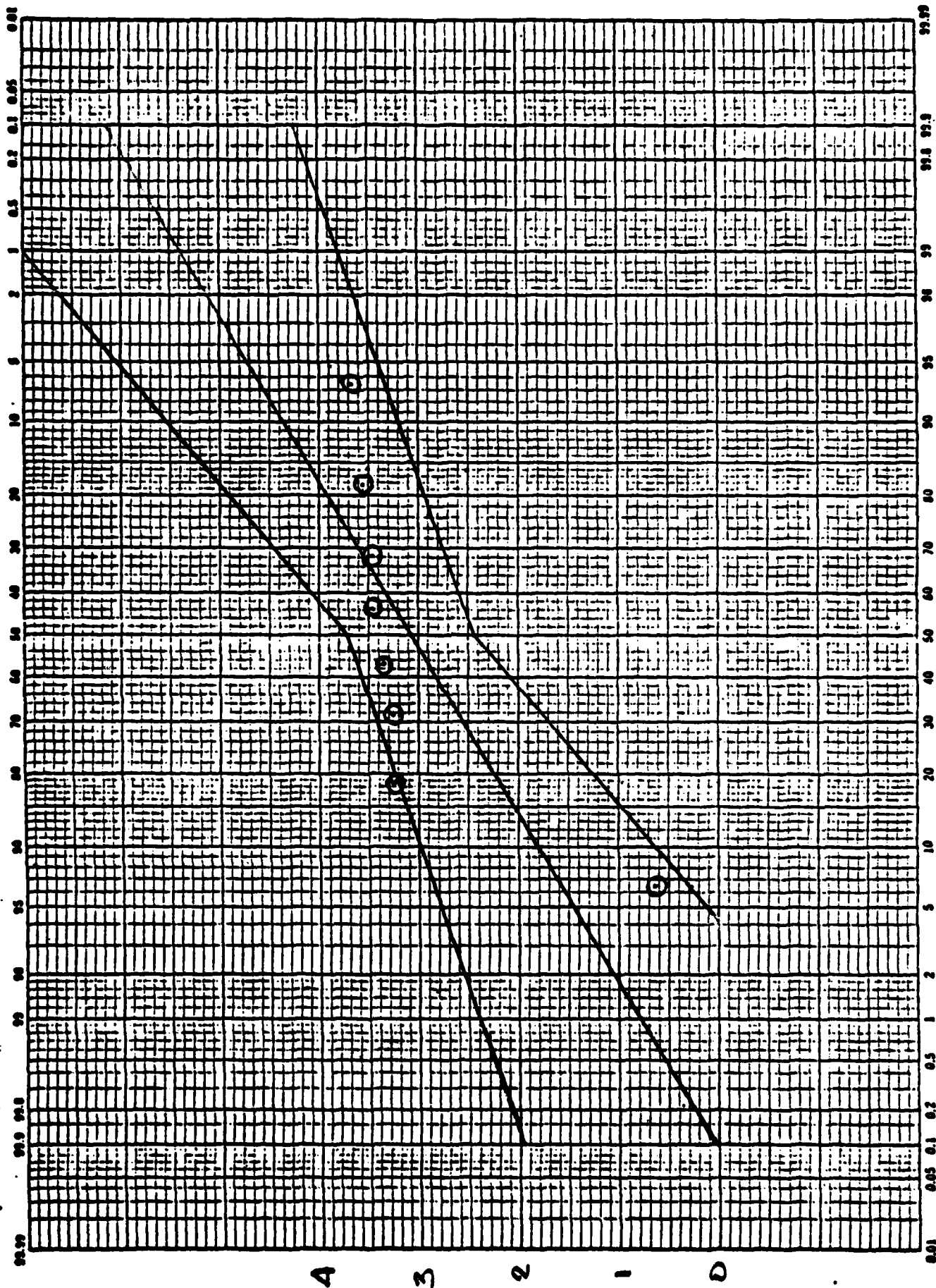Figure 13 - MOD "g" Phase II Low Angle

21
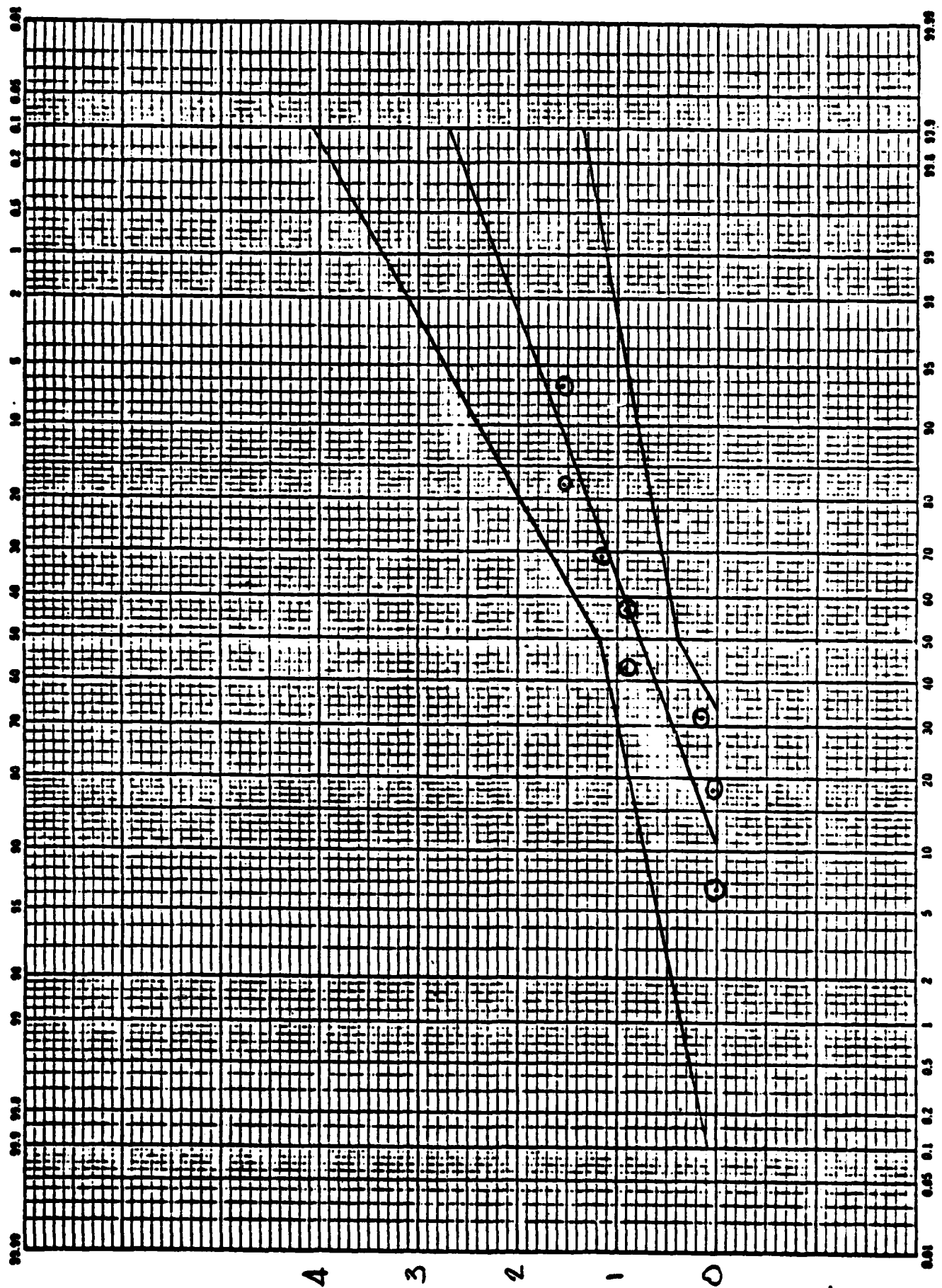
Figure 14 — MBA Phase II Low Angle

Figure 15 — MOD "g" Phase II Low Angle

23
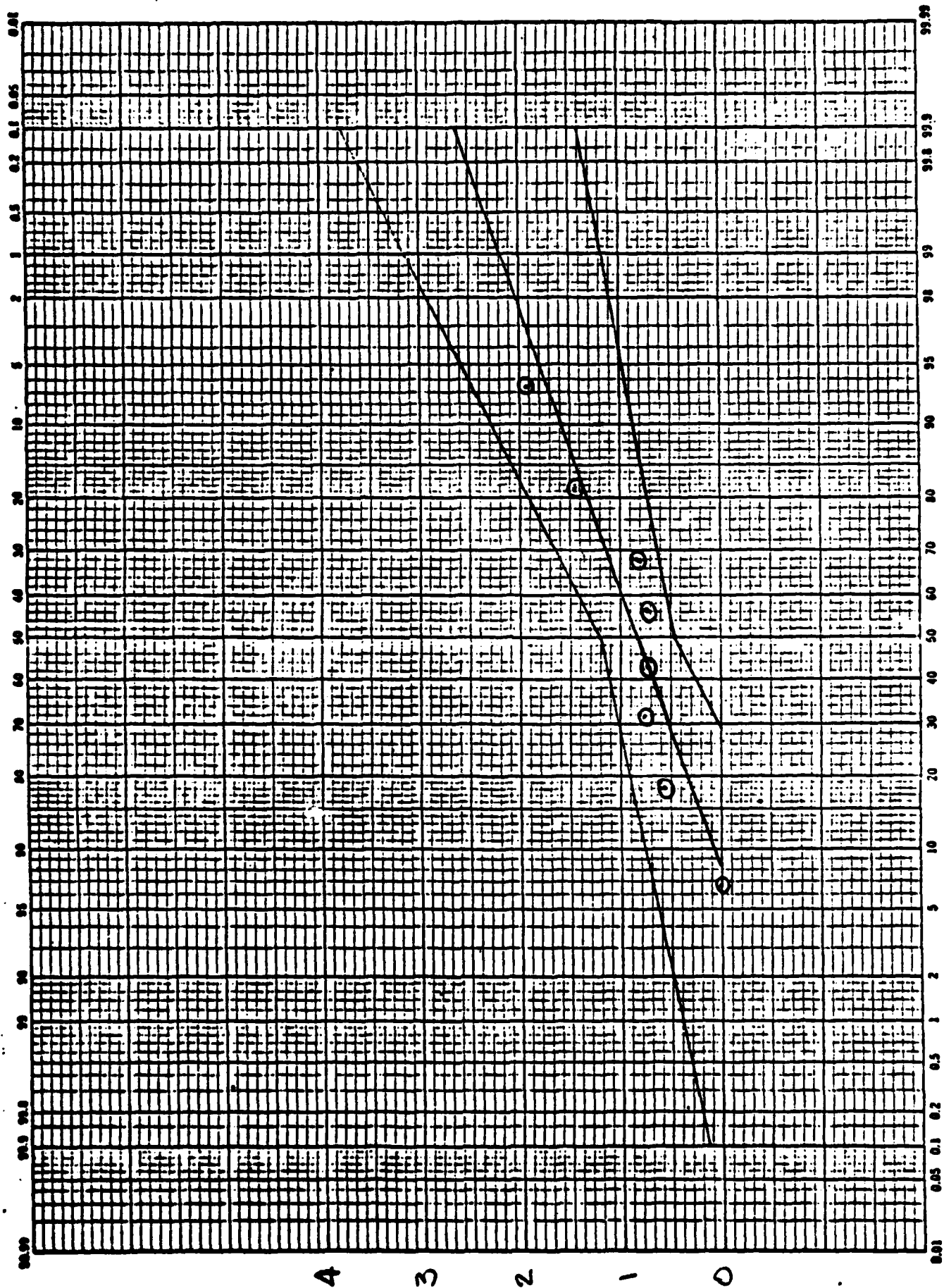
Figure 16 – MBA Phase II Low Angle

24
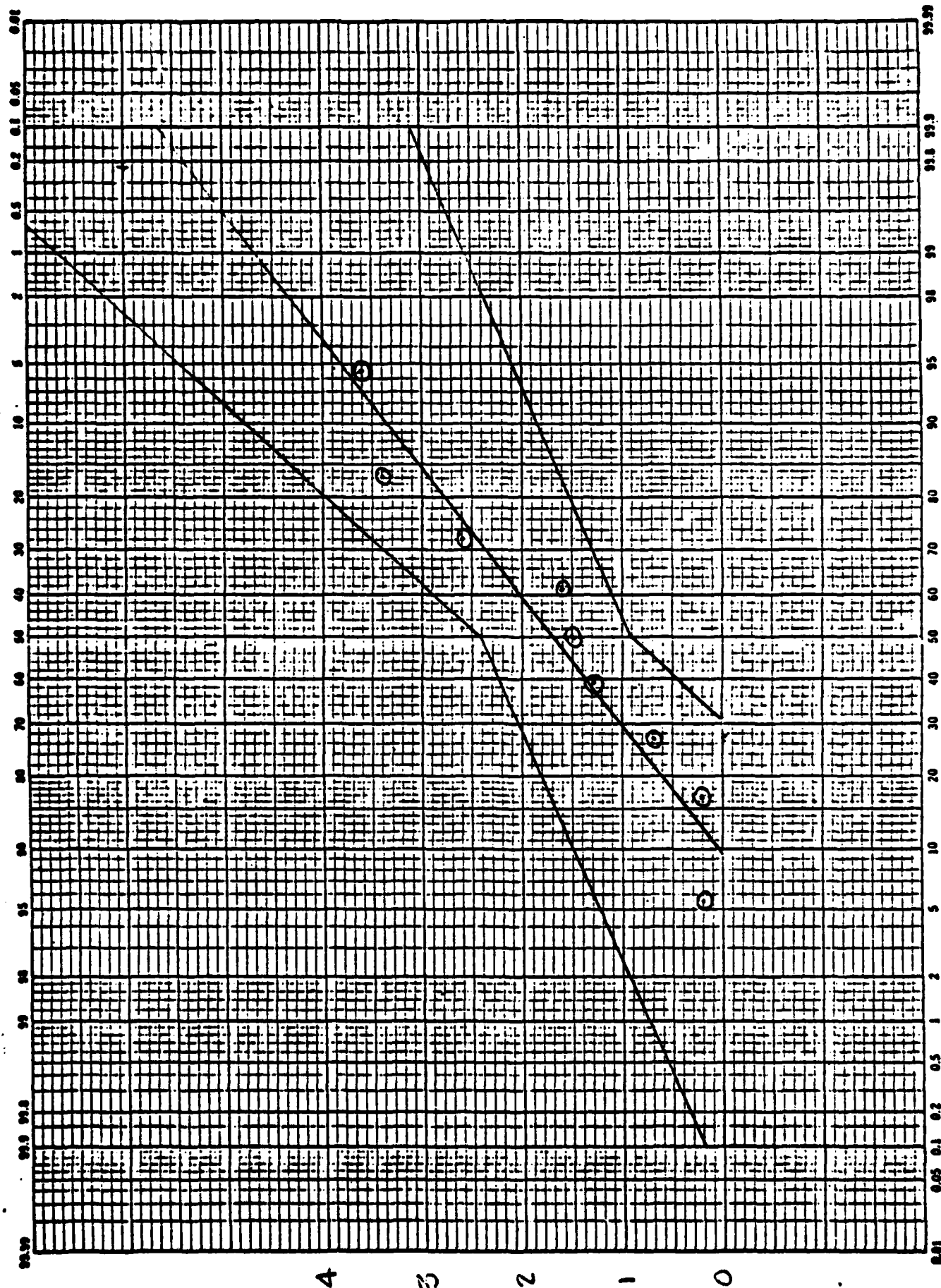
Figure 17 - MBA Phase III Low Angle

number of fuzes that will either exceed or be less than a certain value. Using Figure 10 as an example, the intersection of the lower curve with zero, (20), shows the cumulative number of events that would not yield visible results or conversely, 100 less the intersection value which will give visible results. Because the curve is the 90% confidence envelope, this condition is stated as follows:

"You can be 90% confident that 80 times out of 100 the observer will see a cloud."

These results for each individual test and the MOD "E" and $TiCl_4$ composites are shown in the bar chart of Figure 4.

The center line between the 90% confidence lines is included on the figures because it represents the average line or 50% confidence curve. The test points are ordered in increasing values and plotted on the figures using the procedures given in the reference. Note that, for the most part, all data points fall within the 90% confidence envelope and that approximately 50% fall on either side of the 50% confidence curve.

The composite 90% confidence performance of the MOD "E" and the $TiCl_4$ configurations are approximately equal. The MOD "E" has a lower average observed intensity, but also a lower dispersion about the average than the $TiCl_4$, which yields good high confidence values. The $TiCl_4$, although some 40% higher than the MOD "E" in average observed intensity, experienced a lower reliability and, therefore, a higher dispersion. It can be expected that with reliability improvements, the $TiCl_4$ configuration will show much better results. For instance. if the $TiCl_4$ reliability is improved to match the MOD "E" configuration, some 92 out of 100 of the $TiCl_4$ clouds would be visible at 90% confidence.

1.8   Contract Add-On

In the month of January 1980, MBA was informed of a contract add-on for $9,250 for 576. XM747E Practice Fuzes, for additional testing at Ft. Sill and ARRADCOM.

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1.9   Plans for Next Period

Fabricate and assemble XM747E fuze assemblies for shipment on February 29, 1980.

1.10   Expenditures

Expenditures for January 1979 through January 1980, $89,500.

ATTACHMENT A

SUMMARY - FT LEWIS TEST RESULTS

FUZE, PRACT XM747E-, PROJ 155MM, XM904
(155MM HOW M114A1 - CHG M4A2/5)

DATE	RND	FUZE/SMOKE	PROJ MOD	QE	RNG OF OBSER (KM)	RESULTS
FEB 72						
				PHASE I		
18	8	E2/E	4-Hole	LA	1.8	FAIR TO GOOD SMOKE & FLASH
	8	E2/QRI	"	LA	TO	POOR SMOKE & FLASH (ELIMINATE IN PH II)
	8	E2/MBA	"	LA		FAIR SMOKE, NEGLIGIBLE FLASH
	5	M739	M107/T2	LA	4.0	CONTROLS
				PHASE II(1)		
19	8	E2/E	4-Hole	LA	1.8	POOR TO FAIR SMOKE
	8	E2/MBA	"	HA	TO	GOOD TO EXCELLENT SMOKE (SELECT FOR PHASE III)
(AM)	8	E2/E	"	LA		POOR SMOKE
	8	E2/MBA	"	HA		POOR SMOKE
	3	M739	M107/T2	2 LA. 1 HA	2.0	CONTROLS
				PHASE III		
19	9(2)	E2/MBA	4-Hole	LA	1.8	POOR TO FAIR SMOKE & FLASH
	1	E2/E	"	LA	TO	POOR TO FAIR SMOKE & FLASH
(PM)	10	M739	T2	LA		FLASH/SMOKE SMALL - NOT PERSISTENT
	10	M739	H6	LA		BETTER THAN T2 TYPE
	3	E1/E	NONE	LA		VERY POOR
	1	M739	M107/T2	LA	2.0	CONTROLS
TOT	98					

(1) INADVERTENTLY SEVEN XM904 PROJECTILES W/90° HOLES WERE FIRED AMONG PROJECTILES W/45° HOLES WITHOUT ASSOCIATION TO FUZE/ROUND COMBINATION.

(2) FIRST THREE ROUNDS WERE PROJECTILES WITH 90° HOLES. ALL OTHERS HAD 45° HOLES.

DATA & SUMMARY SUPPLIED BY ARRADCOM

PHASE I - OBSERVER ANALYSIS
155MM XM804 TRAINING PROJECTILE WITH 4 EACH ½" DIA SMOKE PORTS

TEST DATE: DEC. 18 1979

LEGEND

1. U = UNOBSERVED
2. P = POOR
3. F = FAIR
4. G = GOOD
5. VG = VERY GOOD
6. EX = EXCELLENT

OBSERVERS: GT-80 · AREA DCOM 400M · MTA(150-1475) · AREA DCOM 200M · AREA DCOM 180M · FF. C/LL 200M

TYPE FUZE	TEST SERIES	SMOKE 1	2	3	4	5	6	7	FLASH 1	2	3	4	5	6	7	RATING SUMMATION
MOD's	1	4	F	G	?G	?G	?G	G						X		23
	2	4 3	P	F	G	G	G	F						X		23
	3	? ?	U	F	U	U	U	F								15
	4	1 1	U	U	U	G	U	U								10
	5	2 2	U	U	P	G	U	U						?		15
	6	6 6	G	P	G	G	G	G	X							27
	7	5 G	G	G	G	VG	G	G	X X	X	X					32
	8	5 G	G	F	G	G	G	G	X X		X			X		29
	TOTAL															174
ORI	1	1	U	U	U	U	U	U								8
	2	3 2	P	G	G	G	F	G								22
	3	1	U	U	U	G	P	U								8
	4	1 1	U	U	U	G	P	U					X			10
	5	4 3	U	U	G	P	P	P	X X	X						16
	6	4	F	F	U	J	U	P	X X	X				X	X	19
	7	1 1	U	U	U	U	U	U								7
	8	4 5G	G	F	G	G	G	VG	X X	X	X			X	X	32
	TOTAL															122
MBA	1	1	U	U	J	P	P	P								15
	2	3 U	U	G	G	G	G	G	X X							22
	3	1	U	U	G	F	F	P								14
	4	3 4	U	F	U	F	F	F								18
	5	1 2	U	U	P	P	P	P								11
	6	1 2	U	U	P	P	P	U								12
	7	6 G	G	G	G	G	G	VG	X X	X				X	X	32
	8	4 4	F	U	G	U	F	F	P							21
	TOTAL															143

PHASE II - OBSERVER ANALYSIS
155MM XM804 TRAINING PROJECTILE
WITH 4 EACH ½" DIA PORTS
LOW ANGLE - QE 522 MILS

TEST DATE: DEC. 19, 1977 (A.M.)

LEGEND
1. = UNOBSERVED
2. = POOR
3. = FAIR
4. = GOOD
5. = EXCELLENT

OBSERVERS

TYPE FUSE	TEST SERIES	SMOKE 1	2	3	4	5	6	7	8	9	10	11	FLASH (1–11)	RATING SUMMATION
MODE	1	1	1	1	1	1	1	1	2	1	1	1		13
	2	3	4	4	3	2	2	2	2	1	3	2		27
	3	1	1	1	1	1	1	1	1	1	1	1		11
	4	4	5	4	4	3	3	2	4	1	3	4		39
	5	3	2	3	1	1	1	1	1	3	1	1		19
	6	3	4	3	3	2	2	2	3	1	3	2		29
	7	5	5	5	4	3	3	3	4	1	4	3		38
	8	4	3	4	3	3	2	1	2	4	2	2		30
TOTAL														205
MBA	1	2	2	3	2	2	2	1	1	1	1	1	X	18
	2	5	5	5	4	4	3	4	4	4	4	5	X	47
	3	5	5	5	4	4	4	3	5	4	4	5		48
	4	5	5	5	4	4	4	4	5	4	4	5		49
	5	5	5	4	4	4	4	4	4	5	5	5		50
	6	4	5	5	4	4	4	3	5	4	4	5		47
	7	4	5	4	4	4	4	4	5	5	5	5		49
	8	4	5	5	4	5	4	5	5	5	5	5		51
TOTAL														358

NOTE:
INADVERTENTLY SEVEN XM804 PROJECTILES WITH 90° HOLES WERE FIRED AMONG PROJECTILES WITH 45° HOLES IN PHASE II WITHOUT ASSOCIATION TO TYPE OF FUSE/ROUND COMBINATION.

PHASE II - OBSERVER ANALYSIS
155MM XM804 TRAINING PROJECTILE
WITH 4 EACH ½" DIA PORTS
HIGH ANGLE - QE 1054 MILS

TEST DATE: DEC. 19, 1979 (AM)

LEGEND
1 - UNOBSERVED
2 - POOR
3 - FAIR
4 - GOOD
5 - EXCELLENT

Data table — Observers (SMOKE columns 1–11), FLASH columns 1–11, RATING SUMMATION:

TYPE / FUSE	TEST SERIES	SMOKE 1	2	3	4	5	6	7	8	9	10	11	RATING SUMMATION
MOD 'E'	1	3	2	3	3	2	2	3	2	3	3	3	28
	2	2	1	1	1	1	1	1	1	1	1	1	12
	3	1	1	1	1	1	1	1	1	1	1	1	11
	4	3	5	2	5	2	2	2	1	1	1	1	21
	5	3	3	3	3	3	1	3	4	3	2	2	28
	6	1	1	1	1	1	1	1	1	1	1	1	15
	7	2	3	3	3	1	1	4	1	2	3	1	24
	8	2	2	2	3	1	2	2	1	2	2	2	21
	TOTAL												158
MBA	1	2	2	2	3	2	2	2	1	1	1	1	18
	2	5	5	5	2	2	2	2	4	2	2	2	27
	3	1	1	1	1	1	1	1	1	1	1	1	11
	4	2	3	2	2	1	1	3	1	3	1	2	18
	5	2	2	2	2	2	2	1	1	1	1	1	18
	6	1	1	3	3	2	2	1	1	1	1	1	20
	7	1	2	2	2	1	2	1	2	1	2	1	17
	8	1	4	4	4	2	3	3	4	5	2	3	30
	TOTAL												161

NOTE:
INADVERTENTLY SEVEN XM804 PROJECTILES WITH 90° HOLES WERE FIRED AMONG PROJECTILES WITH 45° HOLES IN PHASE II WITHOUT ASSOCIATION TO TYPE OF FUSE/ROUND COMBINATION.

PHASE II - OBSERVER ANALYSIS
155MM XM 804 TRAINING PROJECTILE
WITH 4 EACH ½" DIA PORTS
LOW ANGLE - QE 522 MILS

TEST DATE: DEC. 19, 1979 (P.M.)

OBSERVERS: MBASSOCOM 155M, ARRADCOM 155M, ARRADCOM 200M, TRAMBELAIN? CILL, ...

TYPE FUSE	RD NO.	SMOKE 1	2	3	4	5	6	7	8	9	10	FLASH 1	2	3	4	5	6	7	8	9	10	RATING SUMMATION
MBA	1	3	3	?	?	?	3	?	3	2	5	X					?	?		?		12
MBA	2	4	3	4	3	4	3	3	4	3	5	X		X	X		X	X		X		56
MBA	3	2	2	3	2	2	2	3	2	3	4	X			X		X	X		X		25
MBA	4	2	3	2	1	2	2	3	2	3	3	X										23
MBA	5	1	1	1	1	1	1	2	1	2	1	X					X	X	X	X		12
"E"	6	3	3	2	1	2	2	3	2	3	3	X			X		X	X	X	X		1
MBA	7	3	3	1	2	3	2	3	3	3	3	X			X		X	X		X		26
MBA	8	5	4	5	4	5	5	5	5	4	5	X			X		X	X		X		46
MBA	9	?	?	1	1	?	1	2	3	1	3	X			X			X				17
MBA	10	5	5	5	3	5	3	4	5	5	5	X			X		X	X		X		44
	TOTAL																					241

NOTE:

FIRST THREE (3) MBA ROUNDS WERE XM804 PROJECTILES WITH 90° HOLES ALL OTHERS HAD 45° HOLES

ATTACHMENT B

How to Use Probability Paper to Solve Materials Problems

It can help you

1. *Set specification limits*
2. *Check material or process performance over a period of time*
3. *Check a supplier's claims*

by **Donald Peckner**, *Associate Editor, Materials in Design Engineering*

□ Application of statistical quality control principles is simplified when arithmetic probability paper is used. This type of paper has as its abscissa a probability scale, and as its ordinate a linear arithmetic scale on which the variable is plotted.

On a probability plot, a large amount of data, which may extend over a wide range, is condensed to only two numbers: the arithmetic mean $\bar{X}$, and the estimate of the standard deviation, s. For most engineering purposes, the arithmetic mean and the estimate of standard deviation, together, furnish the information necessary so that a material can be used.

Since 50% of the total number of observations will be above, and 50% below, the arithmetic mean, the intercept of the ordinate and the 50% abscissa can be read to obtain the mean directly.

To obtain the value of s, another well-known property of the normal distribution is used. On probability paper the area under the curve between the 16% and 84% abscissas is equivalent to the value of $\bar{X} \pm s$. Therefore, determining the intercept of the curve with the 84% abscissa and subtracting $\bar{X}$ will give the value of s directly.

How to plot the data

The next few paragraphs describe how to plot data on prob-

TABLE 1—CUMULATIVE PERCENTS CORRESPONDING TO VARIOUS SAMPLE SIZES

Observation Number	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	5	4.5	4.2	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.7
2	15	13.6	12.5	11.5	10.7	10.0	9.4	8.8	8.3	7.9	7.5	7.1	6.8	6.5	6.25	6.0	5.8	5.6	5.4	5.2	5.0
3	25	22.7	20.8	19.2	17.8	16.7	15.6	14.7	13.9	13.2	12.5	11.9	11.4	10.9	10.4	10.0	9.6	9.3	8.9	8.6	8.3
4	35	31.8	29.2	26.9	25.0	23.3	21.9	20.6	19.4	18.4	17.5	16.7	15.9	15.2	14.6	14.0	13.5	13.0	12.5	12.1	11.7
5	45	40.9	37.5	34.6	32.1	30.0	28.1	26.4	25.0	23.7	22.5	21.4	20.4	19.6	18.75	18.0	17.3	16.7	16.1	15.5	15.0
6	55	50.0	45.8	42.3	39.2	36.7	34.4	32.3	30.6	28.9	27.5	26.2	25.0	23.9	22.9	22.0	21.2	20.4	19.6	19.0	18.3
7	65	59.1	54.2	50.0	46.4	43.3	40.6	38.2	36.1	34.2	32.5	30.9	29.6	28.3	27.1	26.0	25.0	24.1	23.2	22.4	21.7
8	75	68.2	62.5	57.7	53.5	50.5	46.9	44.1	41.7	39.5	37.5	35.7	34.1	32.6	31.25	30.0	28.9	27.8	26.8	25.9	25.0
9	85	77.3	70.8	65.4	60.7	56.7	53.1	50.0	47.2	44.8	42.5	40.5	38.7	37.0	35.4	34.0	32.7	31.5	30.4	29.3	28.3
10	95	86.4	79.2	73.1	67.8	63.3	59.4	55.9	52.8	50.0	47.5	45.2	43.2	41.3	39.6	38.0	36.6	35.2	33.9	32.8	31.7
11		95.5	87.5	80.8	75.0	70.0	65.6	61.8	58.4	55.3	52.5	50.0	47.7	45.7	43.75	42.0	40.4	38.9	37.5	36.2	35.0
12			95.8	88.5	82.1	76.7	71.9	67.7	63.9	60.5	57.5	54.7	52.2	50.0	47.9	46.0	44.2	42.6	41.1	39.7	38.3
13				96.2	89.2	83.3	78.1	73.6	69.4	65.8	62.5	59.5	56.8	54.4	52.1	50.0	48.1	46.3	44.6	43.1	41.7
14					96.4	90.0	84.4	79.3	75.0	71.1	67.5	64.4	61.4	58.7	56.25	54.0	51.9	50.0	48.2	46.6	45.0
15						96.7	90.6	85.4	80.6	76.4	72.5	69.1	65.9	63.1	60.4	58.0	55.8	53.7	51.8	50.0	48.3
16							96.9	91.2	86.1	81.6	77.5	73.9	70.5	67.4	64.6	62.0	59.6	57.4	55.4	53.7	51.7
17								97.1	91.7	86.9	82.5	78.6	75.0	71.8	68.75	66.0	63.5	61.1	58.9	56.9	55.0
18									97.2	92.2	87.5	83.4	79.6	76.1	72.9	70.0	67.3	64.9	62.5	60.4	58.3
19										97.4	92.5	88.1	84.1	80.5	77.1	74.0	71.2	68.5	66.1	63.8	61.7
20											97.5	88.6	88.6	84.3	81.25	78.0	75.0	72.2	69.6	67.3	65.0
21												97.7	93.2	89.2	85.4	82.0	78.8	75.9	73.2	70.7	68.3
22													97.7	90.5	89.6	84.0	82.7	79.6	76.8	74.2	71.7
23														97.9	93.75	86.0	85.5	83.3	80.4	77.6	75.0
24															97.9	94.0	90.4	87.0	83.9	81.1	78.3
25																98.0	94.2	88.7	87.5	84.5	81.7
26																	98.1	94.4	91.1	88.0	85.0
27																		98.1	94.6	91.4	88.3
28																			98.2	94.9	91.7
29																				98.3	95.0

1—*Distribution of tensile strength on arithmetic probability paper is accurate check on material performance.*
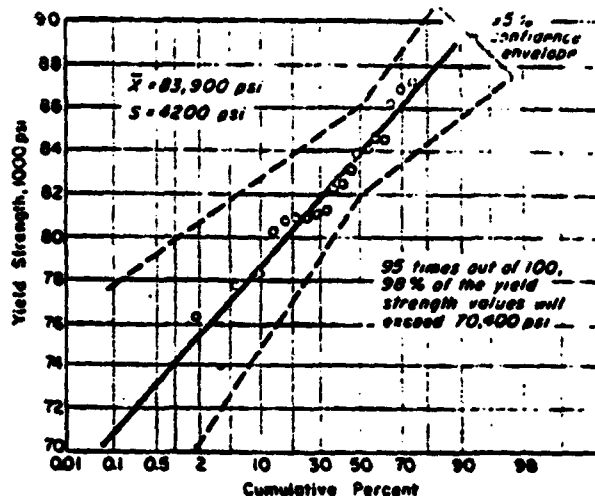
2—*Distribution of yield strength forecasts minimum expected values for use in setting specification limits.*

ability paper in two situations: 1) when the number of data is small, and 2) when the data are available in large quantities that cannot be conveniently handled without grouping.

After arranging the data so that cumulative percentages can be obtained and plotted, the next step is to determine the scatter of data that might be encountered. This can be done by making use of the confidence envelope which is described in detail in an accompanying box.

When the number of data is small (30 or less)—Arithmetic probability paper, in this case, is used as follows:

1. Arrange the data in order

of increasing magnitude and assign each datum point a cumulative percentage value from Table 1.

2. Choose an appropriate scale on the abscissa and plot the data against the appropriate cumulative percentage value on the ordinate.

Table 2 is an example of random numbers rearranged and assigned a cumulative percentage from Table 1.

When the number of data is large—When more than 30 observations must be plotted, the method just described becomes both lengthy and tedious. The procedure is varied as follows:

1. Tabulate the number of observations that lie in equal-sized intervals. The interval should be at least 10 times the last significant figure to which the values are measured.

2. Calculate the percentage of

observations in each interval and determine the cumulative percentage in and below the interval.

3. Plot the cumulative percent on the probability scale against the *top* of each interval on the abscissa.

A typical arrangement of data is shown in Table 3.

How probability paper can be used

To check material performance —Fig 1 demonstrates the use of arithmetic probability paper to check performance of a material. The data represent a permanent mold cast aluminum alloy with a specified minimum tensile strength of 25,000 psi. Data were obtained over a three month period. As seen in Fig 1:

1. Average tensile strength to be expected is 26,650 psi.

2. By inspection, the intercept of the specification minimum and the curve indicates that 26% of

TABLE 2—ARRANGING DATA FOR USE WITH TABLE 1

Observation	Rearranged, Magnitude Increasing	Cumulative Percent*
477	370	4.2
370	440	12.5
491	463	20.8
463	471	29.2
440	477	37.5
505	478	45.8
506	486	54.2
508	491	62.5
471	493	70.8
486	496	79.2
478	506	87.5
493	508	95.8

*Taken from Table 1.

TABLE 3—ARRANGING LARGE NUMBERS OF OBSERVATIONS

Interval, arbitrary units	Number of Observations In Each Interval	Observations In Each Interval, %	Cumulative Percent
6.01-6.10	1	0.5	0.5
6.11-6.20	9	4.5	5.0
6.21-6.30	36	18.0	23.0
6.31-6.40	68	34.0	57.0
6.41-6.50	57	28.5	85.5
6.51-6.60	24	12.0	97.5
6.61-6.70	4	2.0	98.5
6.71-6.80	1	0.5	100.0*

*This number cannot be plotted since, theoretically, it is at infinity on this scale.
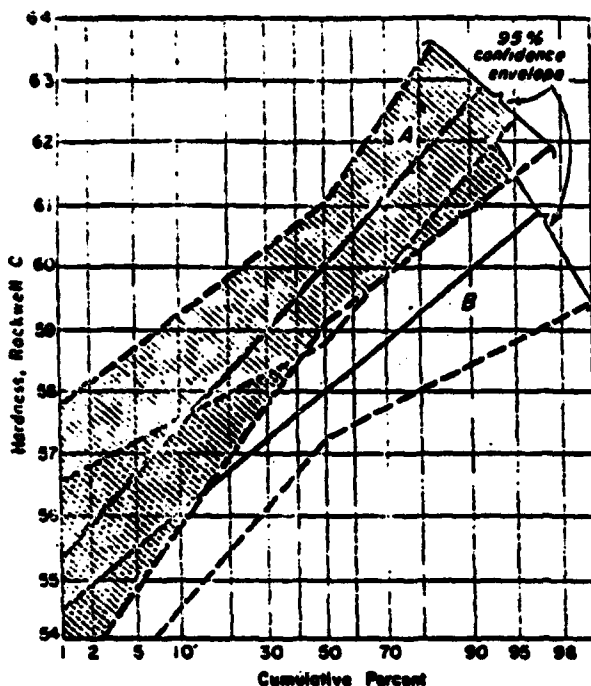
3—Two groups of hardness data are compared. Since confidence envelopes do not overlap at the 50% ordinate, the groups are different and Process A will produce better results than Process B 95% of the time.
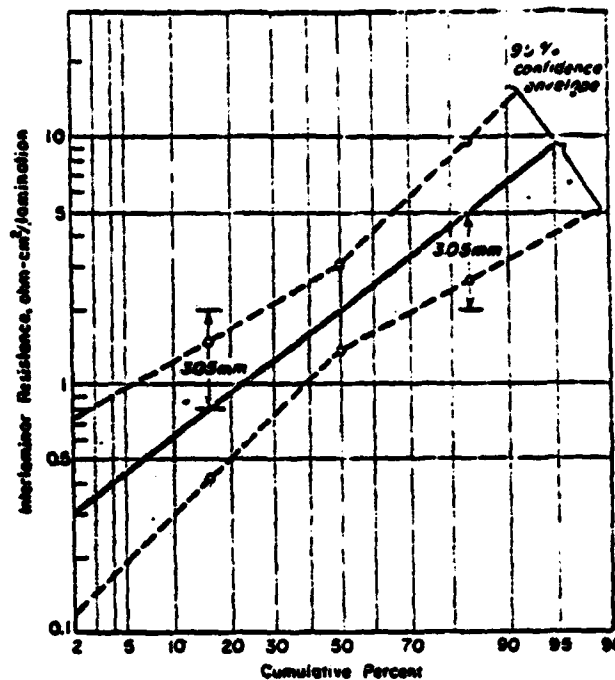
4—Confidence envelope for logarithmic probability paper. Estimate of standard deviation (s) is made equivalent to distance between 50% ordinate and either 16% or 84% ordinate.

the material will probably be below the specification minimum.

3. The confidence envelope indicates that 95 times out of 100, as little as 7.5% and as much as 45% of the material can be expected to exhibit a tensile strength below the specification minimum.

Probability paper, then, shows the engineer how well a material is performing and suggests a course of action to follow. In this case, there are two possible courses: either revise the specification properties in accordance with the facts of actual performance, or choose a new alloy for the application.

To set up specification limits— Take a case where a literature survey turned up a promising casting alloy but, as usual, only average mechanical properties were quoted. Since an arithmetic average gives no indication of values at the extremes of a distribution, a more precise estimate of mechanical properties was needed for specification purposes.

By pouring tensile bars from several experimental heats, it is possible to forecast the minimum

expected values of yield strength, tensile strength, elongation, etc., and incorporate them into a specification. In this use the probability plot in Fig 2 indicates that 95% of the time a specified yield strength of 70,000 psi will be obtained 98 times out of 100.

To compare sets of data—An additional useful application of arithmetic probability paper is the comparison of several sets of data to determine whether they were picked from the same or from different distributions. This is a general engineering problem since many situations occur where a design or process is changed and a decision must be made as to whether a real improvement has been obtained, i.e., an improvement that matches the economic factors involved.

Two heat treating methods gave the hardness results plotted in Fig 3. Although the variation in hardness produced by process A is no less than that produced by process B, a comparison of the arithmetic means ($\bar{X}$) shows that process A will consistently produce higher average hardness

values. Since the confidence envelopes do not overlap at the 50% ordinate, it can be stated with 95% confidence that the two heat treating processes are significantly different.

When data are not normally distributed

One major shortcoming of probability paper should be noted here. If the data do not fall on an approximately straight line when plotted on arithmetic probability paper, this method of analysis cannot be used. Radical deviation from a straight line indicates a skewed distribution (some types of data, such as measurements of interlaminar resistance or stress rupture, seem to be inherently skewed), whereas the scale of the abscissa has been based on a normal distribution. The ease with which the arithmetic mean ($\bar{X}$) and the estimate of standard deviation (s) can be obtained sometimes leads to an artificial "fit" of a straight line to the data with the consequence that invalid data are obtained. If the data are skewed, then $\bar{X}$ and s must be calculated mathematically

or the distribution of logarithms of the observations must be considered.

If logarithms are used, two approaches are possible. In the first, the logarithms of the observations are plotted on arithmetic probability paper. This is often more convenient than using logarithmic probability paper because the scale of the abscissa can be chosen to fit each set of data, while the logarithmic probability paper has a fixed number of cycles. If logarithmic probability paper has a fixed number of standard deviation, s, is obtained by subtracting the log of the 50% value from the log of the value at 84% and expressing s as the difference in logs or in fractions of log cycles.

The confidence envelope—If the logarithms of a set of observations are plotted on arithmetic probability paper, the mechanics of determining the confidence envelope are the same as those noted in the box. If logarithmic probability paper is used, the method for calculating the limits of the confidence envelope is varied slightly. Rather than estimating s on the basis of log differences, measure the distance between the 50% ordinate and 16% or 84% ordinate as shown in Fig 4. This distance is representative of the value of s and may be substituted for s in the equation used to determine the limits of the confidence envelope (see box).

Consult a statistician in planning experiments

The graphical methods just described are excellent tools for evaluating properties of materials and processes after data have been obtained. If possible, the services of a statistician should be obtained *before* a program is run in order to obtain maximum benefits from a minimum of data.

The statistically designed experimental program, as opposed to the normal engineering "one at a time" approach, will vary several parameters at one time. A statistical design may evaluate the existence of interactions between several variables, usually one of the pitfalls of the "one at a

FACTOR k FOR MULTIPLYING THE ESTIMATED STANDARD DEVIATIONS OF $\overline{X}$ AND s TO OBTAIN CONFIDENCE ENVELOPES

Probability Level, %	Sample Size			
	10-15	16-20	21-50	Very Large
90	1.78	1.73	1.71	1.65
95	2.17	2.10	2.06	1.95
99	3.03	2.88	2.79	2.58

The Confidence Envelope

Its significance

In Fig 1-4 note that an "envelope" has been drawn around the curve representing test observations. The confidence level chosen and the confidence envelope associated with it are used to answer the question, "How reliable are the statements that have been made?"

Note also that two sets of similar observations on the same material, plotted on probability paper, will give rise to slightly different distributions. The use of a confidence envelope, which takes into account errors in the mean ($\overline{X}$) and estimate of the standard deviation (s), becomes a necessity if the interval within which a distribution lies is to be determined.

The "confidence level" desired must be determined. For most engineering purposes, the 95% confidence level is generally chosen. The degree of certainty associated with this confidence level will satisfy almost all engineering requirements.

One danger of using too high a confidence level (such as the 99% level) arises from the fact that in many engineering investigations a great many observations cannot be made. Fig 5 on the next page indicates that the degree of reliability increases with the number of observations. It also increases when the confidence level is decreased. In other words, as the width of the confidence envelope decreases, the amount of scatter to be expected in data also decreases. By sacrificing some degree of certainty it is possible to actually increase the practical utility of a statement of material properties.

How to construct it

Drawing the confidence envelope is done on the basis of the following facts:

1. The true arithmetic mean lies within the interval
$$\overline{X} \pm ks / \sqrt{n}$$

2. The true standard deviation lies within the interval
$$s \pm ks / \sqrt{2n}$$

The constant, k, depends on the number of observations and desired confidence level, while n represents the number of observations. The accompanying table lists approximate values of k for different confidence levels and sample sizes.

Using the values of $\overline{X}$ and s derived from Fig 1, the confidence envelope for these observations was derived as follows:

The arithmetic mean lies within the range $\pm ks / \sqrt{n}$. From Fig 1, we note that $\overline{X}$ es $=$ 2550 psi. From the accompanying table, on the basis of a 95% confidence level and 22 observations, $k = 2.06$. Therefore, $ks / \sqrt{n} = \pm (2.06) (2550) / \sqrt{22} = \pm 1120$ psi.

The range of the estimate of the standard deviation is $\pm ks / \sqrt{2n}$. Since k and s remain the same, the interval is $\pm (2.06) (2550) / \sqrt{44} = \pm 790$ psi.

To construct the confidence envelope, at 50 cumulative percent plot two points: one 1120 psi above and one 1120 psi below the curve. At 16 and 84 cumulative percent, plot points 1910 psi (1120 psi + 790 psi) above and below the curve. Connecting the points produces the confidence envelope.

@ 50% plot $\overline{X} \pm KS/\sqrt{n}$

@ 16 plot $(\overline{X} - s) \pm (KS/\sqrt{n} + KS/\sqrt{2n})$

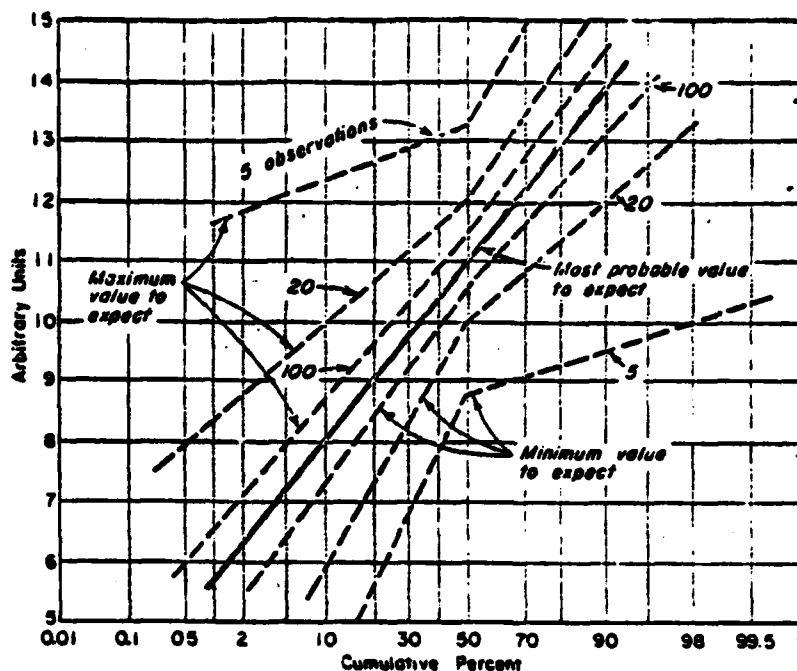@ 84 plot $(\overline{X} + s) \pm (KS/\sqrt{n} + KS/\sqrt{2n})$

time" approach.

Statistical techniques permit the engineer to decide the minimum number of observations necessary to make a reliable decision. Since the cost of making each observation is usually fixed, such knowledge can save the engineer both time and money.

The importance of statistics as a tool for all engineers cannot be overemphasized. It is a particularly valuable tool for those who are required to predict results or formulate additional, and possibly expensive, programs on the basis of a few test results. Large evaluation errors may be made when only a few samples can be taken. Consider, for example, these two diametrically opposed extremes of evaluation errors:

1. A positive result is obtained on the first trial when the probability of obtaining such a result is relatively low. This is an unfortunate situation since a large effort may be expended in an attempt to obtain the original result.

2. The reverse may occur and a negative result is obtained when the probability of obtaining a positive result is relatively high. This places the predictor in the position of, perhaps, discontinuing a potentially successful project. The unfortunate corrollary is that a large and wasteful effort may be made to develop another method when the first would have been the most satisfactory one.

(more E&D on p 171)

5—*Reliability increases as the number of observations increase. A similar effect results when the confidence level is decreased.*

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What Is Probability Paper?

The development of arithmetic probability paper can be visualized as follows: Assume that A represents the standard normal distribution curve of a set of data, the familiar "bell-shaped" curve defined by $\phi(t) = (1/\sqrt{2\pi})e^{-t^2/2}$. Integrating $\phi(t)$ results in a curve similar to B on which is plotted the cumulative percent of observations at or below a given value, against that value. If the abscissa of B is now stretched symmetrically, but nonlinearly, about the 50% value, the curve becomes a straight line (C) and the scale of the abscissa becomes a probability scale. Cumulative percent is plotted on the probability scale since the probability curve represents the integral of the area under the normal probability curve. Cumulative percentages for varying numbers of observations are given in Table 1.

Getting the paper

Two sources for probability paper are: Codex Book Co., Norwood, Mass. (arithmetic—No. 3127, logarithmic—No. 3128), and Keuffel & Esser Co., New York City (arithmetic—No. 359-23, logarithmic—No. 359-22G).

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